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For the classroom

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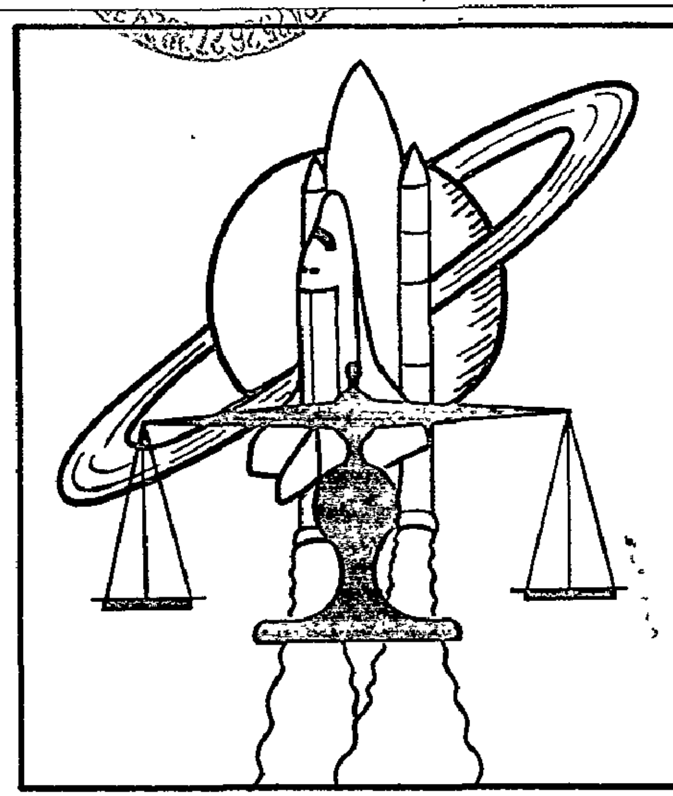
Metrics in Space



When the first Space Stuttle lifted off the launch pad, its five engines produced a thrust of 30 800 000 newtons. Two solid propellant rocket engines burned fuel at a rate of 7 750 kilograms per second and three liquid hydrogen and oxygen engines gulped propellants at a rate of 7 107 liters per second. The 2 022 149 kilogram vehicle rose slowly off the launch pad and picked up speed as the propellants were consumed. By the time an orbital altitude of 275 kilometers was reached, the Orbiter was traveling at a rate of 28 160 kilometers per hour. On return to Earth, friction with the atmosphere raised the Orbiter's underside temperature to 1 755 kelvins. Landing speed on Earth was 333 kilometers per hour.

Metric measurement has become an important part of our space program. To launch a spacecraft into orbit or to send one on a course to another planet requires precise measurement and processing of massive amounts of data in very short periods. Small errors or a lack of precision can lead to a failure to reach orbit or an incorrect course.

The metric system is ideal for use in space research because it is a system that employs the number ten as a base. The units of the system, multiples or submultiples, are reached by multiplying or dividing standard units by ten. The advantage of using this system over the English measurement system is that changing from one unit to another is merely a matter of a simple adjustment of a decimal point while the integers themselves remain untouched. English system measurement requires many different factors. To go from inches to feet, for example, requires the number 12; feet to yards—3; inches to yards—36; feet to miles—5 280; inches to miles—63 360. Keeping factors straight introduces the possibility of error and slows computations.

Another advantage of the metric system over the English system is that the metric unit of mass is constant while the comparable English unit of weight is not. The metric unit of mass, the kilogram, is dependent upon the amount of matter in a given body. It is not dependent upon gravitational attraction. The English units for weight are dependent upon gravitational forces. A 100 pound person on Earth would weigh only 38 pounds on Mars. The same person, using the metric equivalent of 45.5 kilograms, would have the same mass on Mars as on Earth and the same mass even in space under the condition of zero G where there is no weight. (To avoid this problem in the English system, another unit, the pound mass or lbm, is used.)

A still further advantage of using the metric system is that it is the international system of measurement. Many NASA research projects involve international cooperation. The new Spacelab that will be carried in the cargo bay of the Space Shuttle is a product of the nations that make up the European Space Agency. The remote manipulator arm that will be

used to deploy satellites and other payloads from the cargo bay is produced by Canada. Furthermore, many scientific satellites and planetary probes feature experiments designed and constructed by scientists of foreign nations. Using the metric system for space research greatly simplifies cooperative international efforts.

Standard Metric Units

While many metric units are used for aerospace research, some are used with great frequency. These are the units for mass, length, temperature, and time. Other units commonly used are derived units—those based upon one or more base units. Included in this category are the units of volume and force.

When the metric system was developed in France in the late 18th century, the base unit for length, were taken from nature. The meter, or unit of length was defined to be one ten-millionth the distance from the equator to the North Pole along the meridian nearest Paris. Accurate measurement of this distance was difficult and, by chance, the resulting unit was very close to the English yard. The liter, a volume measurement equaling one cubic decimeter or 0.001 cubic meter, came very close to the English quart.

In 1960 the General Conference on Weights and Measures adopted the *Le Systéme International d'Unités* (International System of Units or SI). The modernized units proposed and periodically revised by SI are still based upon natural standards, but these standards are ones that can be measured with greater precision than the arc distance from the equator to the North Pole.

Common Metric System Units

(International System of Units—SI)

meter (m): Unit of length equal to 1 650 763.73 wavelengths in a vacuum of the orange-red line of the spectrum of krypton-86.

gram (g): Unit of mass based upon the mass of one cubic centimeter of water at the temperature of its maximum density.

liter (l): Unit of volume equal to one cubic decimeter.

kelvin (K): Unit of temperature equal to 1/273.15 of the thermodynamic temperature of the triple point of water. The temperature of 0 kelvins is absolute zero. Degrees Celsius is commonly used as a metric unit of temperature. On the Celsius scale, 0 degrees is the freezing point of water and 100 degrees is the boiling point.

newton (N): Unit of force or thrust needed to accelerate a 1 kilogram mass one meter per second squared.

Special Units for Astronomical Studies

astronomical unit (AU): The mean distance from the Earth to the Sun—approximately $1.495\,979 \times 10^{11}$ meters.

light year (ly): The distance light travels in one year's time—approximately $9.460\,55 \times 10^{15}$ meters.

parsec (pa): The parallax shift of one second of arc (3.26 light years)—approximately $3.085\,768 \times 10^{16}$ meters.

speed of light (c): $2.997\,9 \times 10^{8}$ meters per second.

SI Unit Prefixes†

Multiplication Factor	Prefix	Symbol	Pronunciation (USA)*	Term (USA)	Term (Other Countries)
$1\,000\,000\,000\,000\,000\,000 = 10^{18}$	exa	E	ex'a (*a* as in *a*bout)	one quintillion	one trillion
$1\,000\,000\,000\,000\,000 = 10^{15}$	peta	P	as in *pet*al	one quadrillion	one thousand billion
$1\,000\,000\,000\,000 = 10^{12}$	tera	T	as in *terr*ace	one trillion	one billion
$1\,000\,000\,000 = 10^{9}$	giga	G	jig'a (*a* as in *a*bout)	one billion	one million
$1\,000\,000 = 10^{6}$	mega	M	as in *mega*phone	one million	
$1\,000 = 10^{3}$	kilo	k	as in *kilo*watt	one thousand	
$100 = 10^{2}$	hecto	h	heck'toe	one hundred	
$10 = 10$	deka	da	deck'a (*a* as in *a*bout)	ten	
$0.1 = 10^{-1}$	deci	d	as in *deci*mal	one tenth	
$0.01 = 10^{-2}$	centi	c	as in *senti*ment	one hundredth	
$0.001 = 10^{-3}$	milli	m	as in *mili*tary	one thousandth	
$0.000\,001 = 10^{-6}$	micro	μ	as in *micro*phone	one millionth	
$0.000\,000\,001 = 10^{-9}$	nano	n	nan'oh (*an* as in *ant*)	one billionth	one milliardth
$0.000\,000\,000\,001 = 10^{-12}$	pico	p	peek'oh	one trillionth	one billionth
$0.000\,000\,000\,000\,001 = 10^{-15}$	femto	f	fem'toe (*fem* as in *fem*inine)	one quadrillionth	one thousand billionth
$0.000\,000\,000\,000\,000\,001 = 10^{-18}$	atto	a	as in *anato*my	one quintillionth	one trillionth

* The first syllable of every prefix is accented to assure that the prefix will retain its identity. Therefore, the preferred pronunciation of kilometer places the accent on the first syallable, not the second.

† Source: Metric Guide for Educational Materials
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American National Metric Council

Metric/English Conversion Table
(Common Units of Space Research)

	Multiply	*By*	*To Obtain*
Length:	inches	2.54	centimeters
	centimeters	0.393 7	inches
	feet	0.304 8	meters
	meters	3.281	feet
	statute miles	1.609 3	kilometers
	kilometers	0.621 4	statute miles
	kilometers	0.54	nautical miles
	nautical miles	1.852	kilometers
	kilometers	3 281	feet
	feet	0 000 304 8	kilometers
Weight and Mass	ounces	28 350	grams
	grams	0.035 3	ounces
	pounds	0.453 6	kilograms
	kilograms	2.205	pounds
	tons	0.907 2	metric tons
	metric tons	1 102	tons
Liquid Measure	fluid ounces	0.029 6	liters
	gallons	3.785 4	liters
	liters	0 264 2	gallons
	liters	33.814 0	fluid ounces
Temperature	degrees Fahrenheit plus 459.67	0.555 5	kelvins
	degrees Celsius plus 273.15	1 0	kelvins
	kelvins	1.80	degrees Fahrenheit minus 459.67
	kelvins	1.0	degrees Celsius minus 273.15
	degrees Fahrenheit minus 32	0 555 5	degrees Celsius
	degrees Celsius	1.80	degrees Fahrenheit plus 32
Thrust (Force)	pounds force	4.448	newtons
Pressure	newtons	0.225	pounds
	millimeters mercury	133.32	pascals (newtons per square meter)
	pounds per square inch	6.895	kilopascals (1000 pascals)
	pascals	0.007 5	millimeters mercury at 0° C
	kilopascals	0.145 0	pounds per square inch

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Questions and Activities for the Classroom

1. Construct a planetary data table with information such as orbit distance, diameters, and mass converted into metric units.
2. Investigate how the mass of an object on board an orbiting spacecraft might be measured.
3. Why is conversion from unit to unit in the metric system easier and faster than conversions in the English system?
4. Research the history of measurement and the standards units are based upon.
5. Why is the metric system more suited to space science use than the English system?
6. For more information about the metric system, contact the following organization:

   American National Metric Council
   5410 Grosvenor Lane
   Bethesda, MD 20814
   (301) 530-8333

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